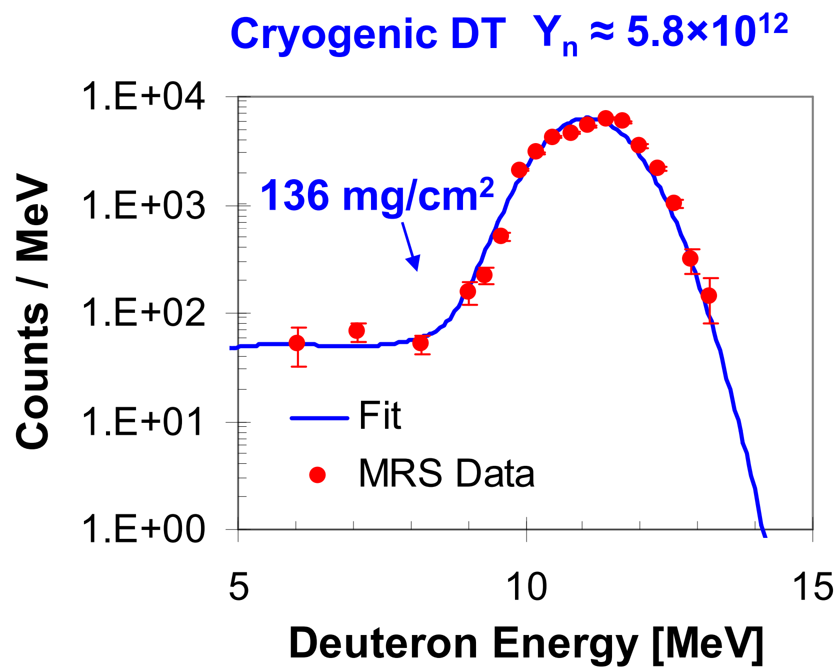
Diagnosing Areal Density using the Magnetic Recoil Spectrometer (MRS) at OMEGA and the NIF

The MRS on OMEGA

Photo: Eugene Kowaluk



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Abstract

A Magnetic Recoil Spectrometer (MRS) has been installed and activated on OMEGA for measurements of down-scattered and primary neutrons, from which areal density, ion temperature, and yield of cryogenic DT implosions can be inferred. To correctly interpret these measurements, the MRS response function was characterized using the Monte Carlo code GEANT4 and diagnostic activation experiments. The results of the MRS characterization as well as measurements of the absolute neutron spectrum at OMEGA will be presented.

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Motivation for the MRS at OMEGA

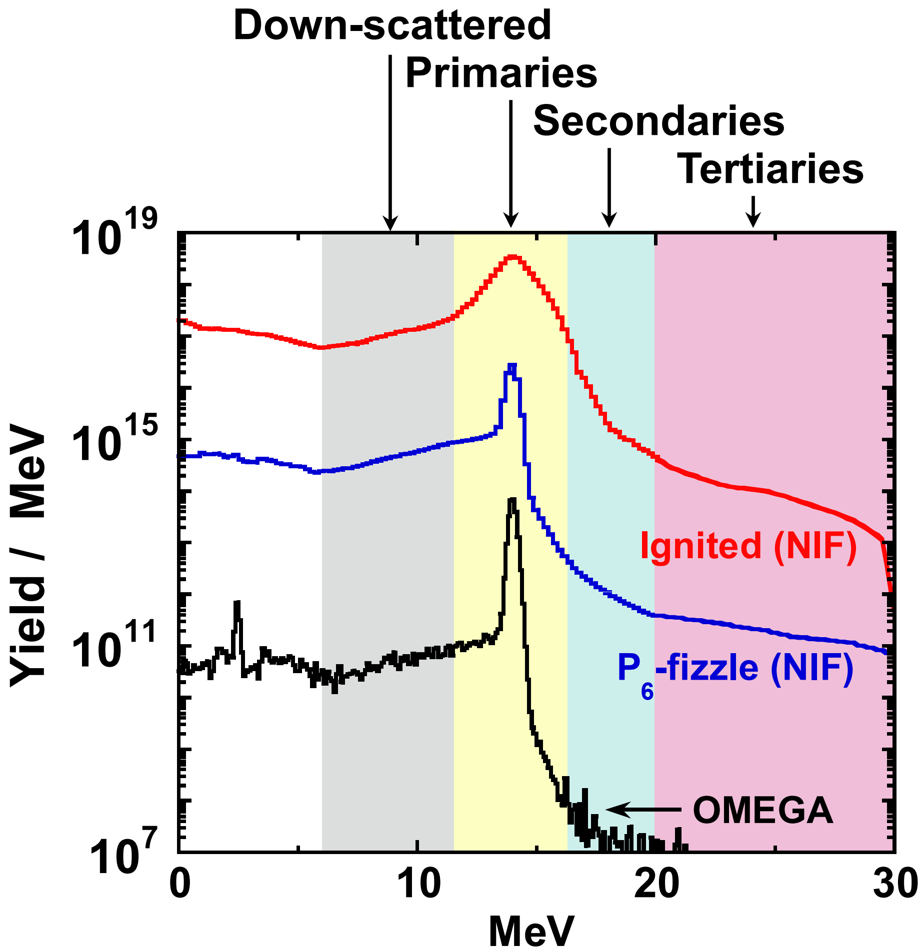
- **Measure the absolute neutron spectrum of cryogenic DT implosions**

- **Infer ρR from the down-scattered neutron spectrum**

- **Measure absolute neutron yield**

- **Determine fuel ion temperature from Doppler broadened primary neutron spectrum and characterize non-thermal features, if present**

The neutron spectrum contains a wealth of information including the ρR, T_i, T_e, and Y_n



From down-scattered (Y_{ds}):

- *ρR* $\frac{Y_{ds}}{Y_{1n}} \propto \rho R$

From primaries (Y_{1n}):

- Y_{1n}
- T_i $T_i \propto \Delta E^2$

From Secondaries (Y_{2n}):

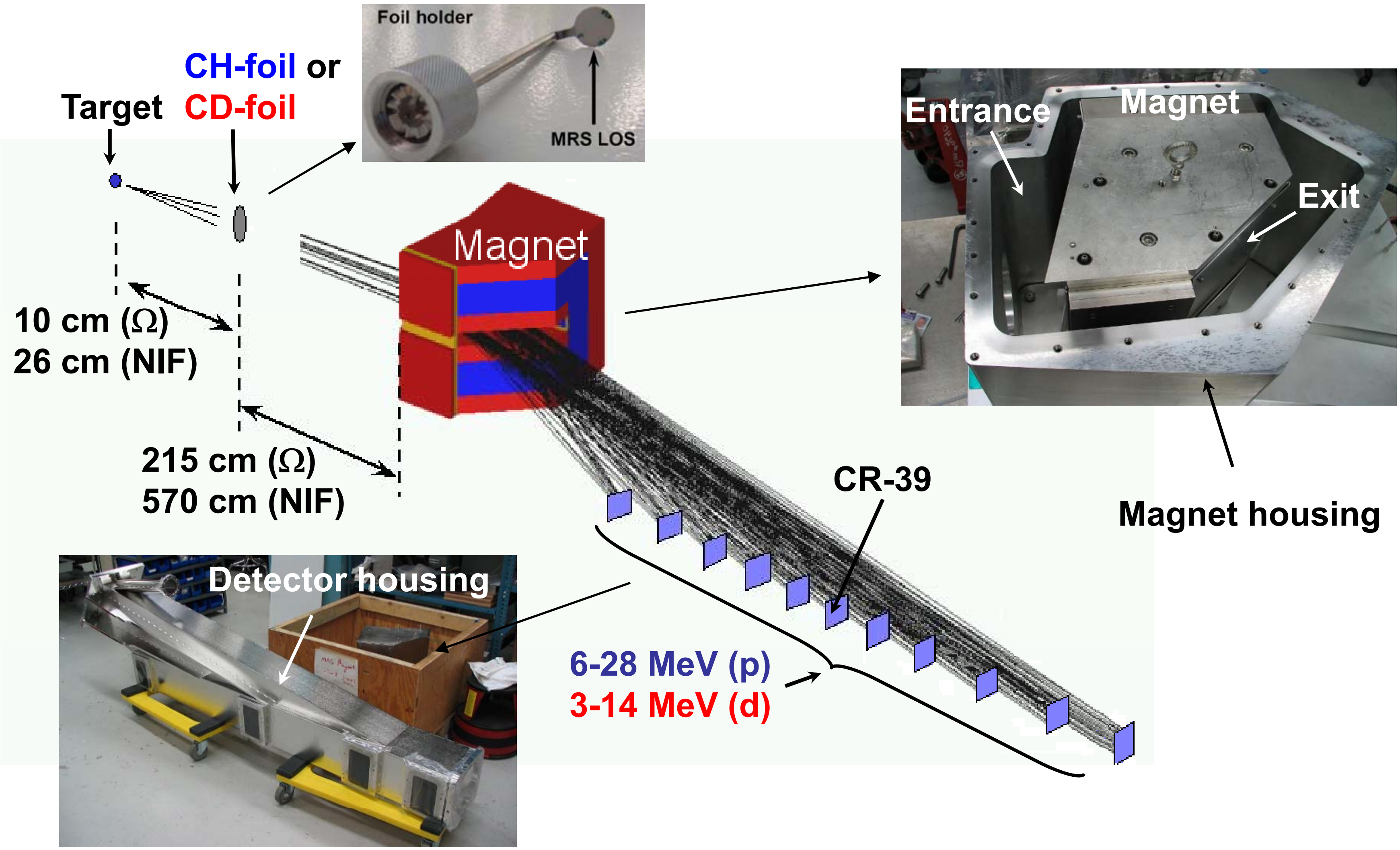
- T_e $\frac{Y_{2n}}{Y_{1n}} \propto T_e^3$

From Tertiaries (Y_{3n}):

- *ρR* $\frac{Y_{3n}}{Y_{1n}} \propto \rho R$

NIF

The principle of the Magnetic Recoil Spectrometer (MRS)



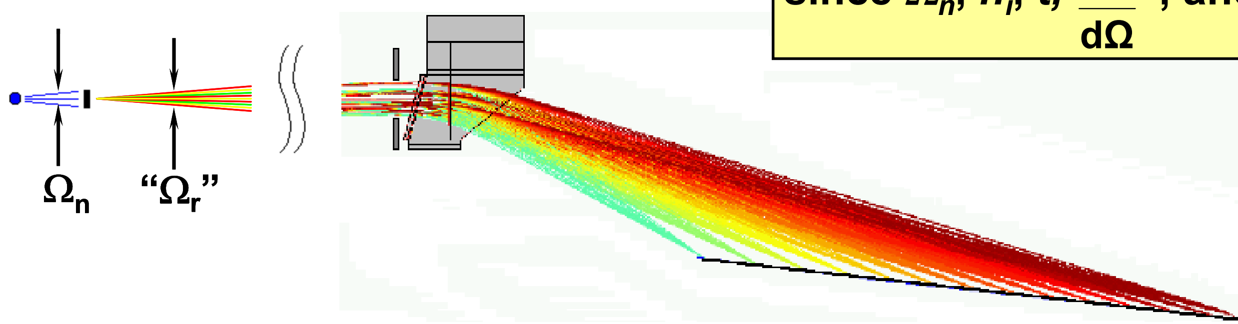
J. A. Frenje et al., Rev. Sci Instrum 79, 10E502 (2008).

MRS detection efficiency and energy resolution

- **The detection efficiency is defined as:**

$$\varepsilon_{MRS} = \frac{\Omega_n}{4\pi} \cdot n_i \cdot t \int^{"\Omega_r"} \frac{d\sigma}{d\Omega_{lab}} d\Omega$$

Absolute yields are measured since Ω_n, n_i, t, $\frac{d\sigma}{d\Omega}$, and Ω_r are known

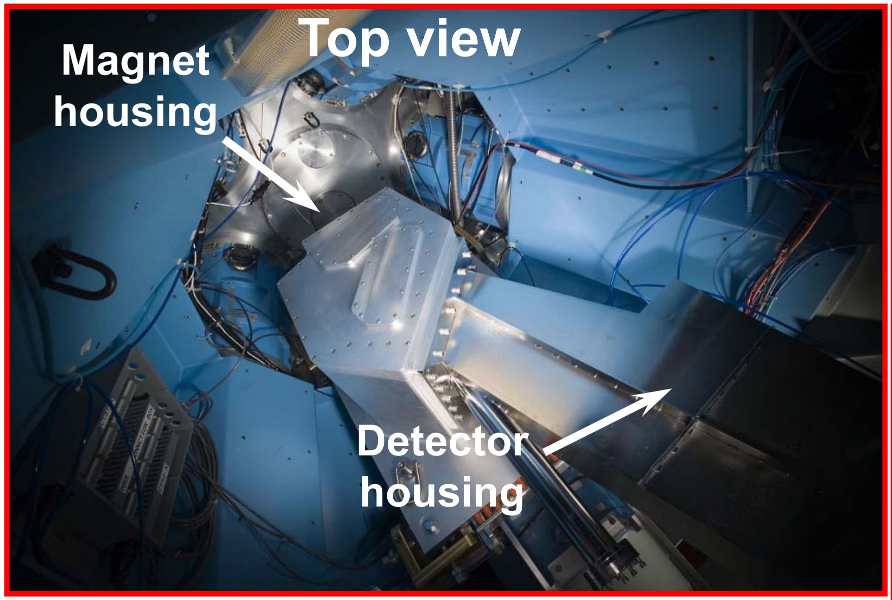


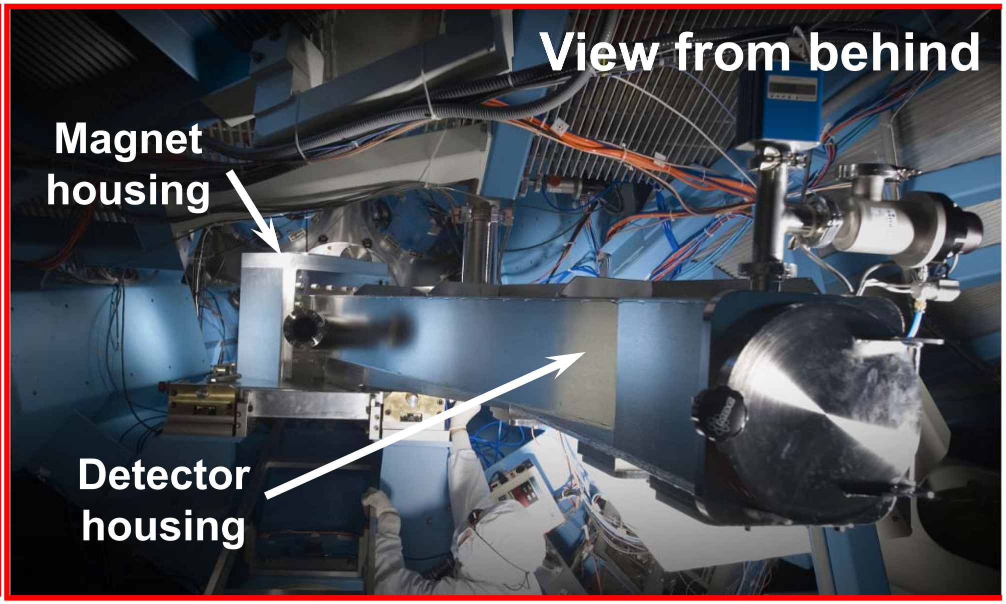
- **Resolution (ΔE_l) is defined as:**

$$\Delta E_l \approx \sqrt{\Delta E_f^2 + \Delta E_k^2 + \Delta E_m^2}$$

ΔE_f	=	Energy loss in foil	$\propto$	foil thickness
ΔE_k	=	Kinematic energy broadening	$\propto$	foil and aperture sizes
ΔE_m	=	Optical energy broadening	$\propto$	magnet performance

The 1st phase of the MRS installation was completed in September 2007

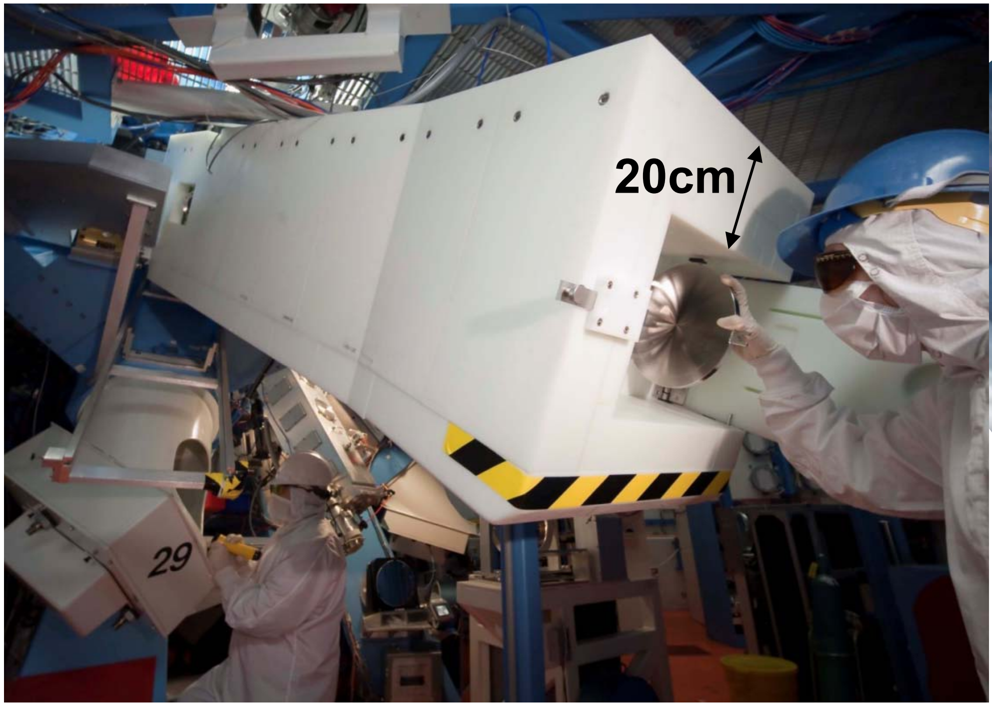


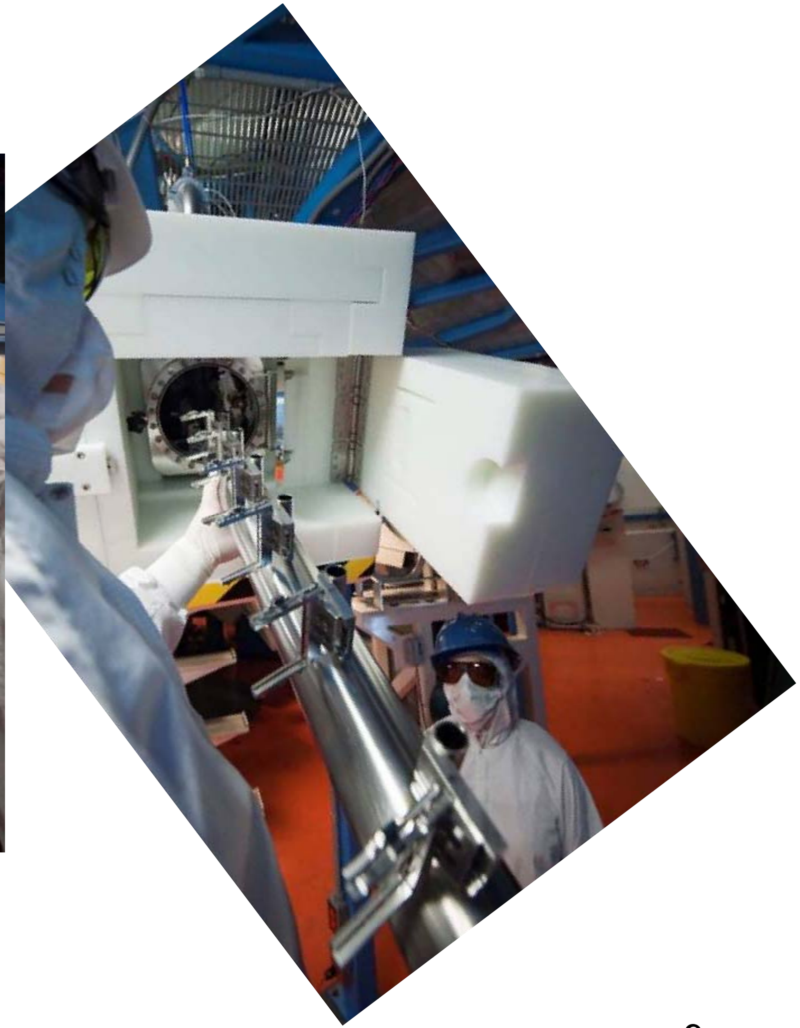


Pictures by Eugene Kowaluk

During the 2nd installation phase, polyethylene neutron shielding was installed around the MRS in Spring 2008

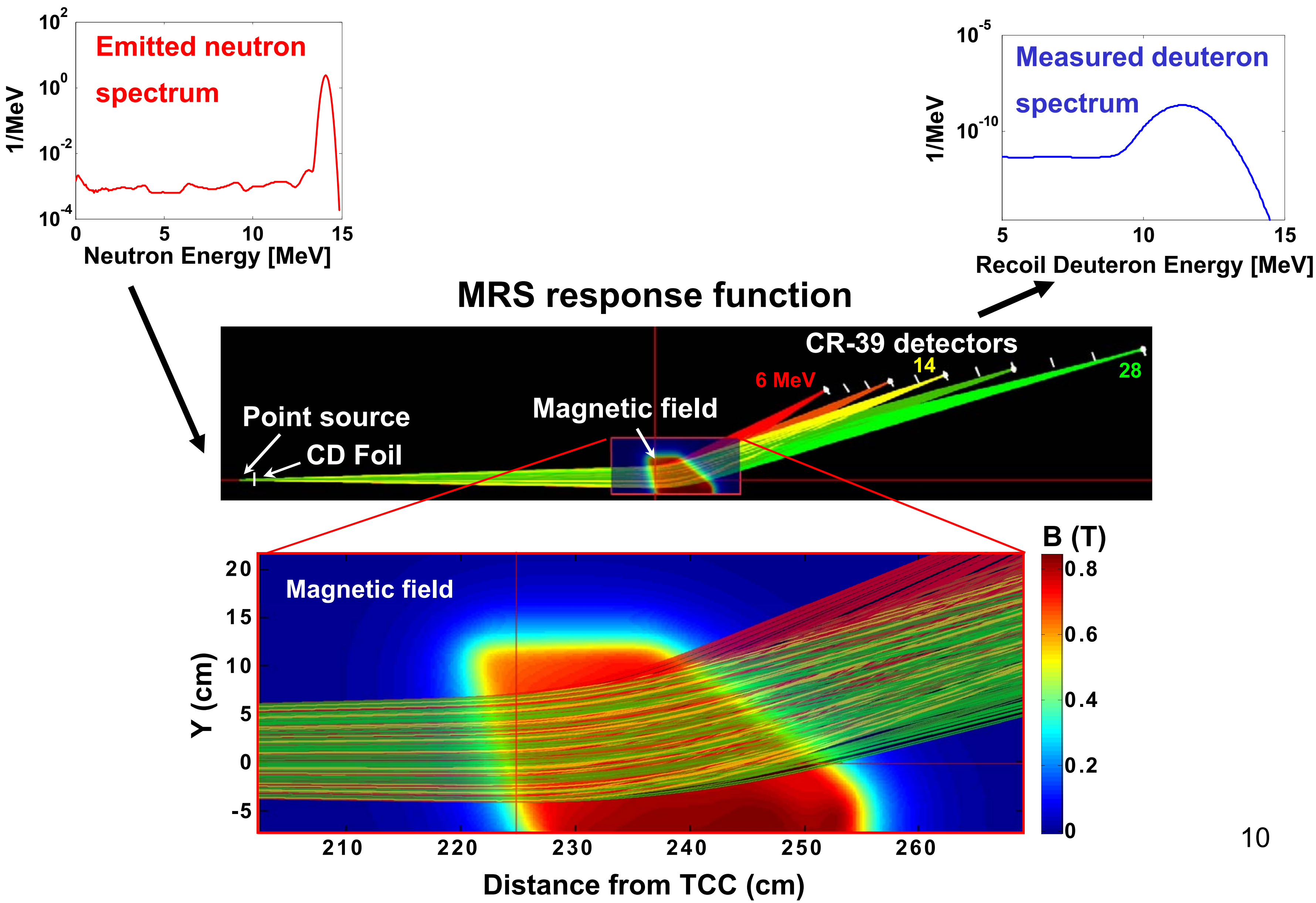
~2000 lbs of polyethylene shielding installed around the MRS



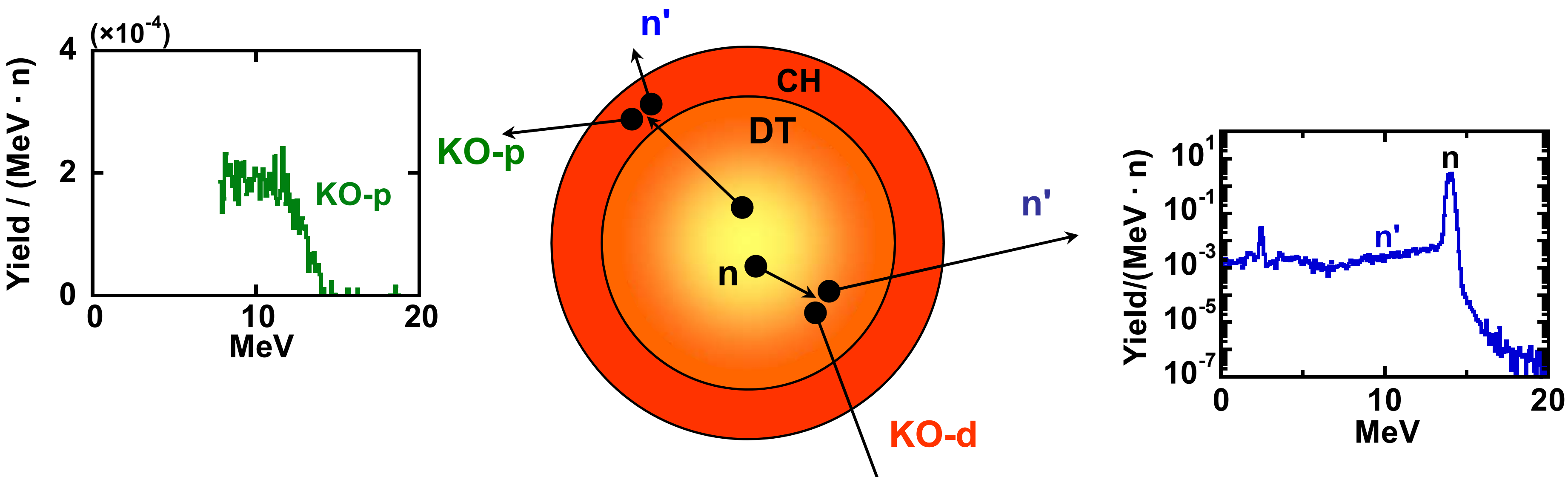


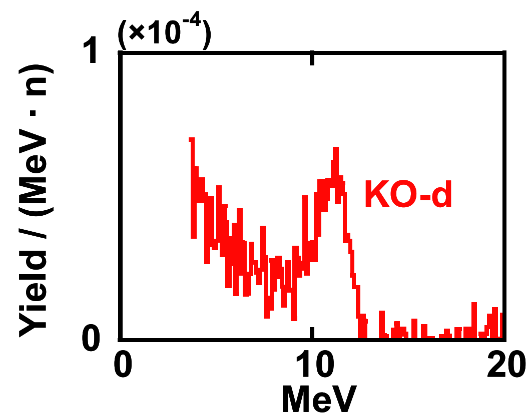
Pictures by Eugene Kowaluk

The Monte Carlo code Geant4 is being used to model the full MRS detector response



Areal density (ρR) can also be inferred from knock-on protons (KO-p), and knock-on deuterons (KO-d)

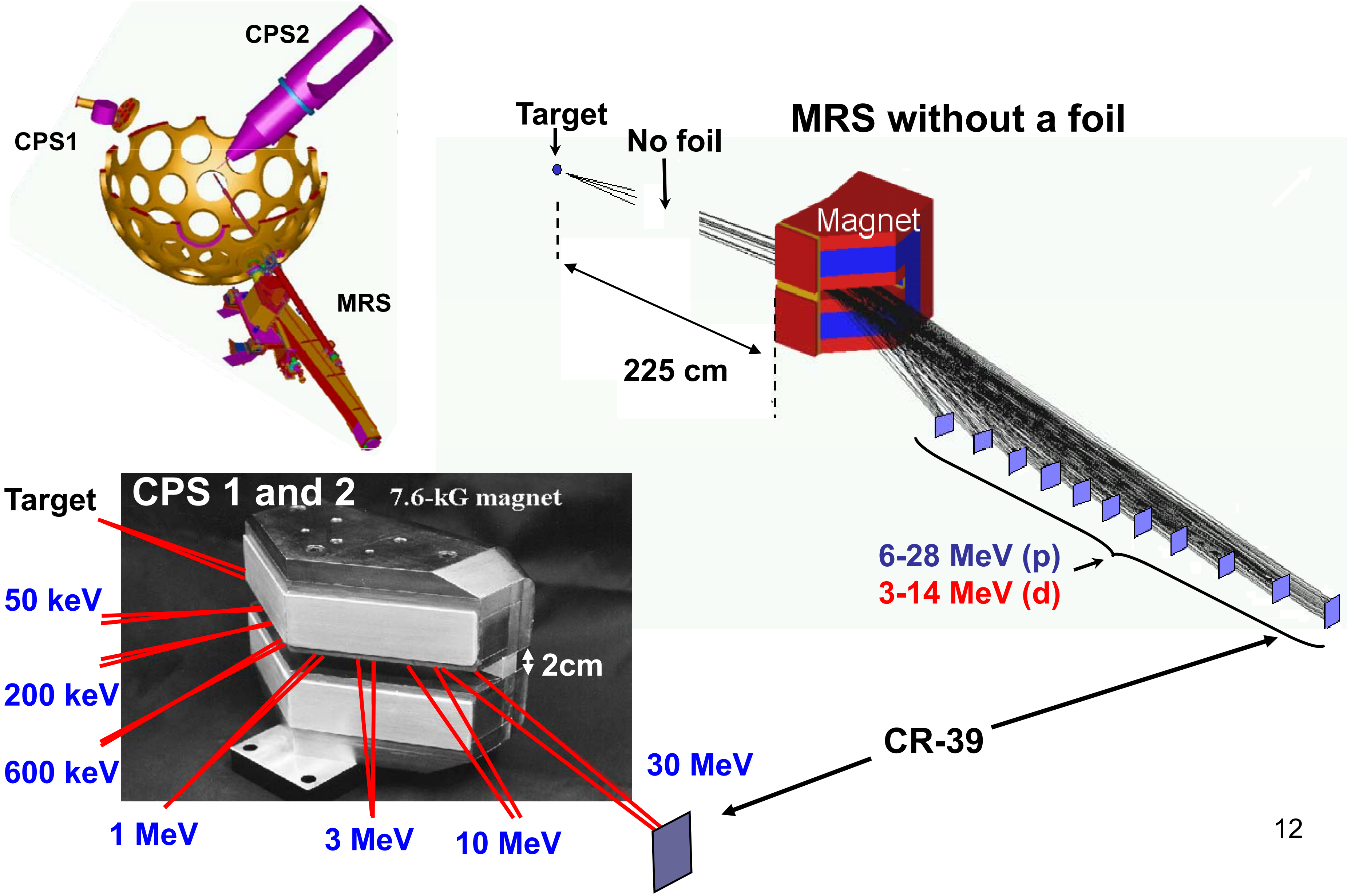




$S \propto \rho R \times Y_n$

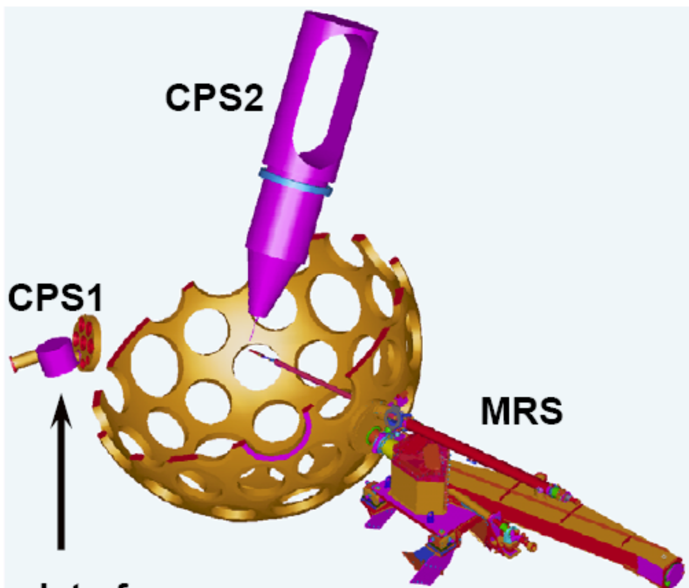
$B \propto Y_n$

KO-p and KO-d measurements are made with magnet based charged particle spectrometers like CPS or the MRS without a foil

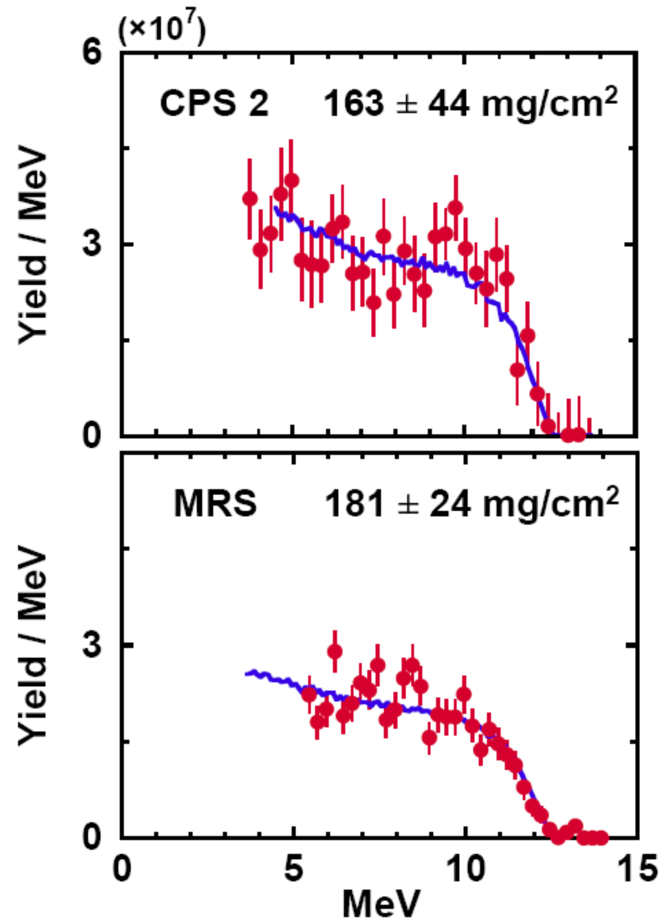


The OMEGA MRS obtained KO-d** data on a cryogenic DT implosion after shielding was installed

Shot 50515 ($Y_n = 2.3\times10^{11}$)

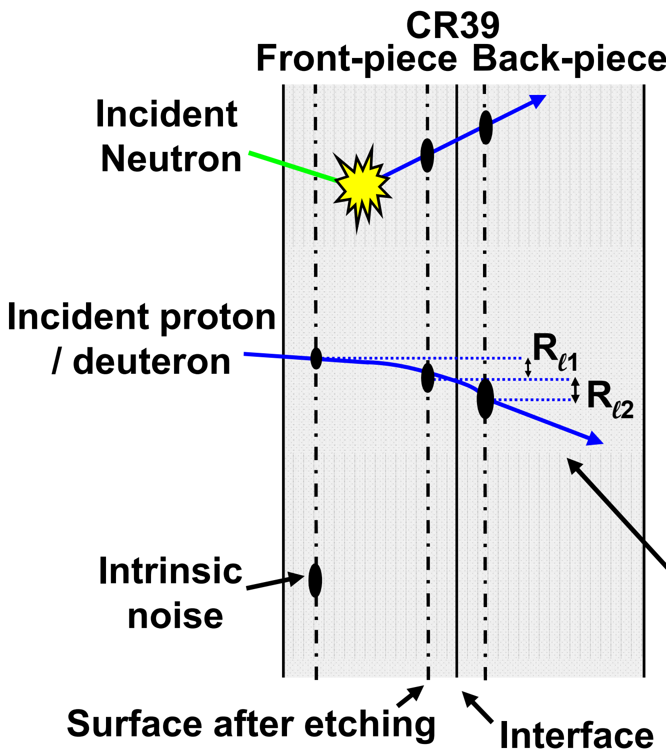


No data from CPS1; sensitivity too low

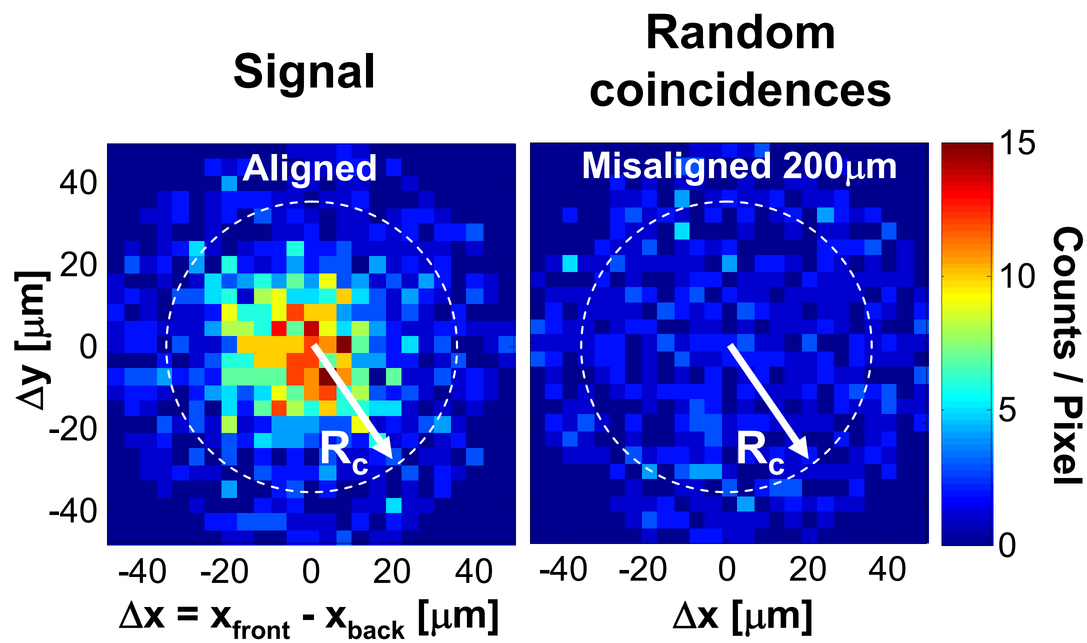


**J. A. Frenje et al., LLE Progress Report for DOE (Jan 2008).

The Coincidence Counting Technique (CCT) is used to reduce the background for DS-n measurements



Triple-track coincidence or double coincidence

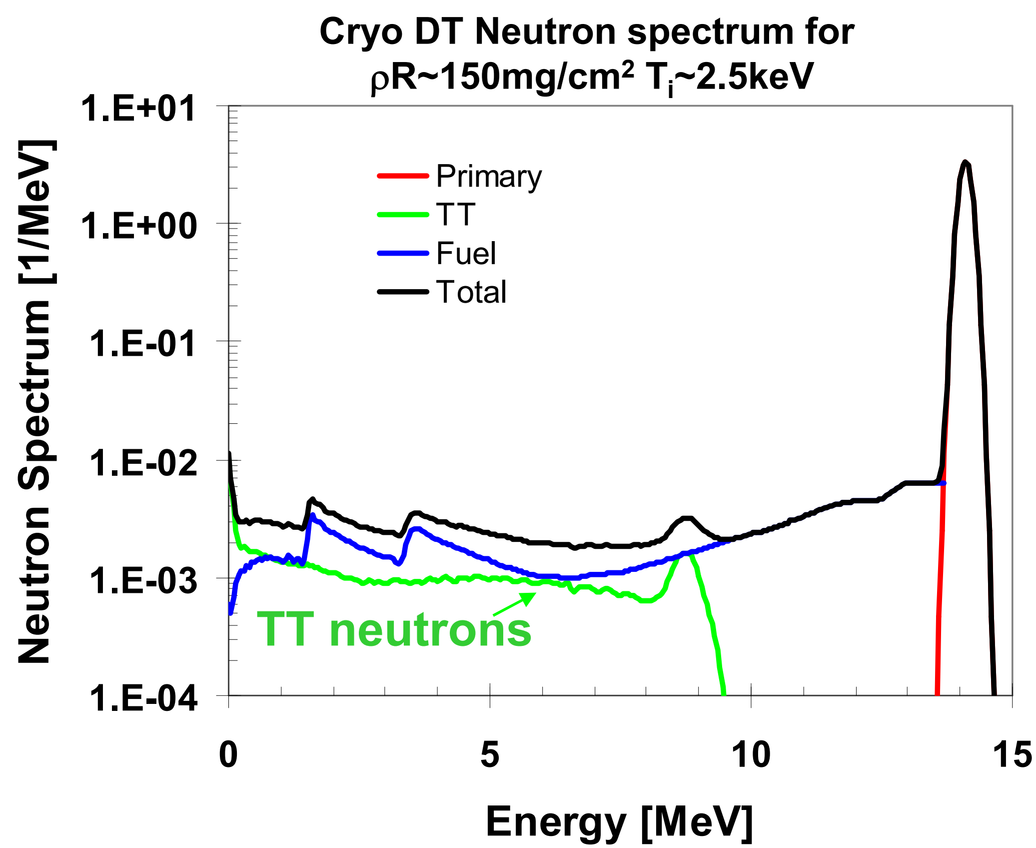


Applying the CCT can enhance the S/B by orders of magnitude in low yield measurements

TT fusion neutrons overlap the lower part of the down-scattered neutron spectrum

Primary TT Neutrons

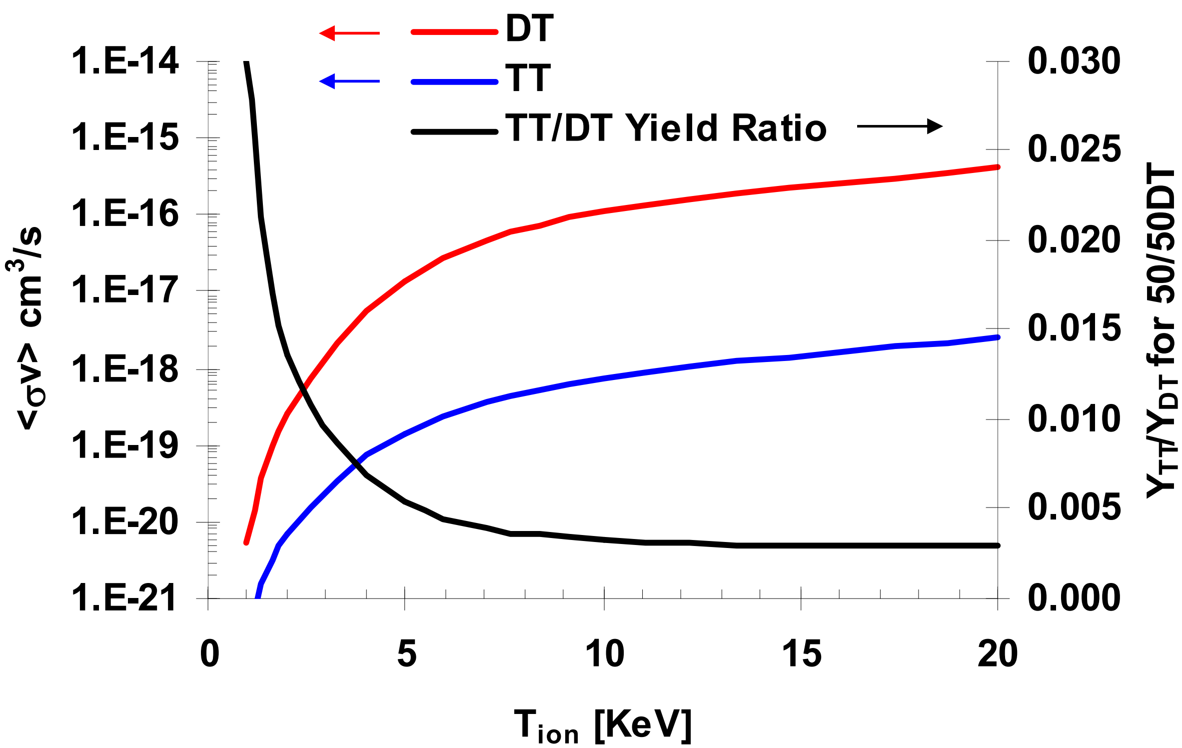
- $T + T \rightarrow \alpha + n + n$
- $T + T \rightarrow \alpha + 2n$
- $T + T \rightarrow {}^{*}He^{5} + n$



For a ~150mg/cm² cryogenic DT neutron spectrum the TT contribution in the MRS down-scattered measurements is ~12%*

*This is for a low resolution measurement of the down-scattered neutron spectrum

The TT contribution to the neutron spectrum is calculated using the reactivity ratio for a given T_{ion}

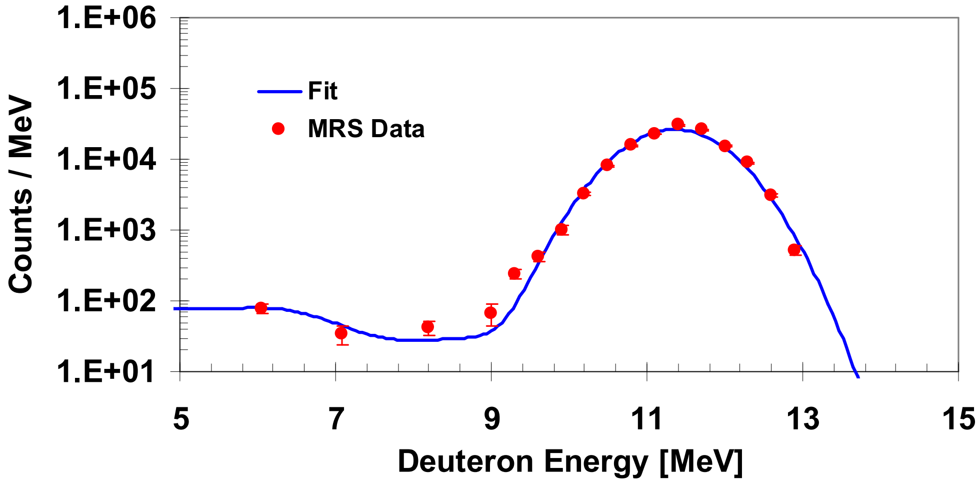


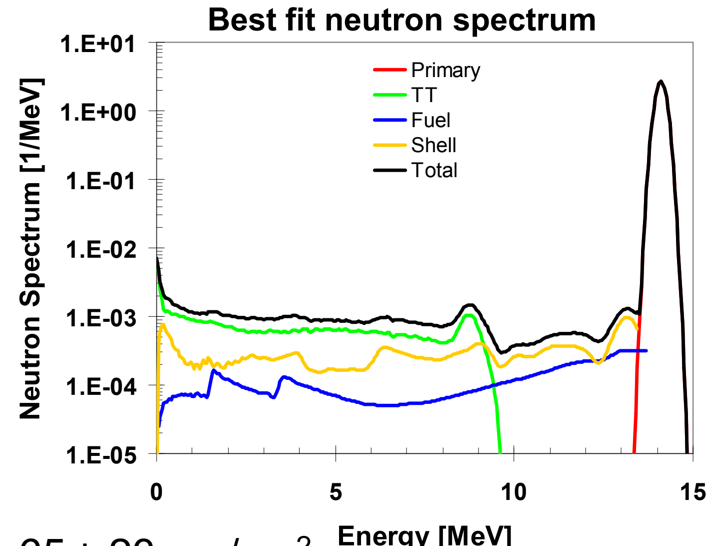
$$Y_{TT} / Y_{DT} \approx \frac{1}{2} \frac{n_T}{n_D} \frac{<\sigma v>_{TT}}{<\sigma v>_{DT}}$$

This assumes approximately equal DT and TT spatial and temporal burn profiles

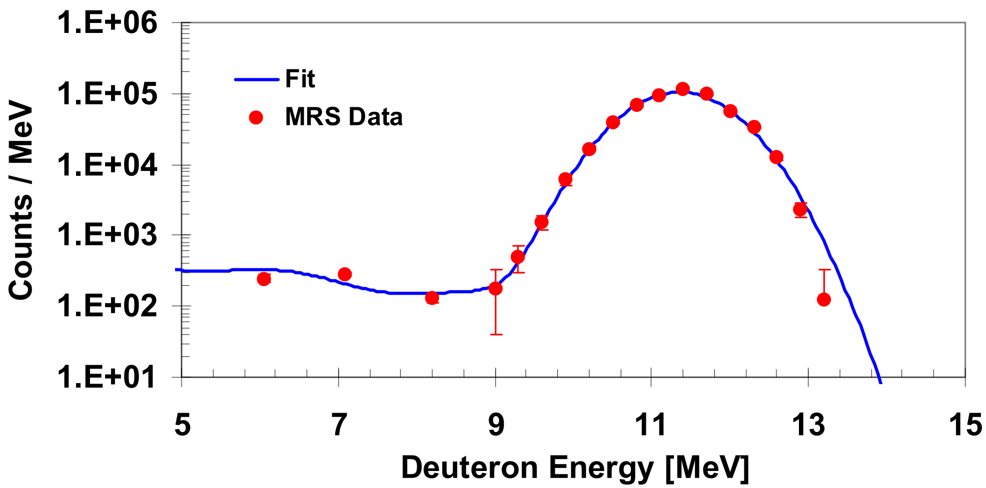
The first DS-n measurements were performed using warm CH DT implosion in April and May 2008

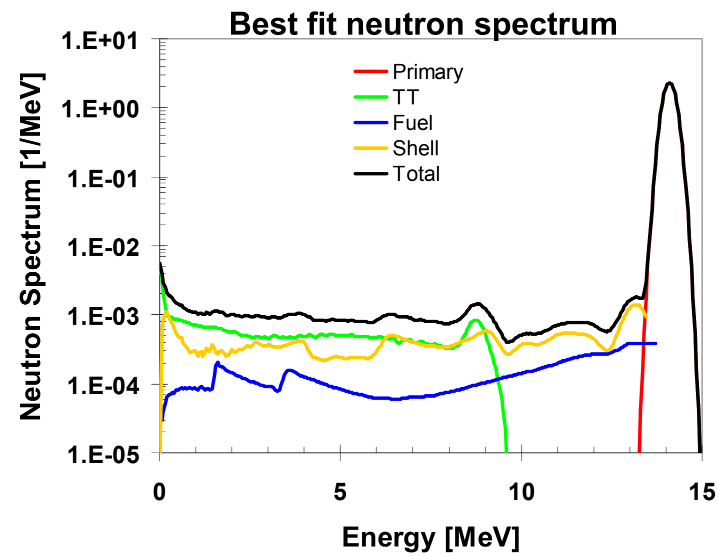
Shots 51294-51298 – ρR_{shell}=45mg/cm^2 ± 20 mg/cm^2





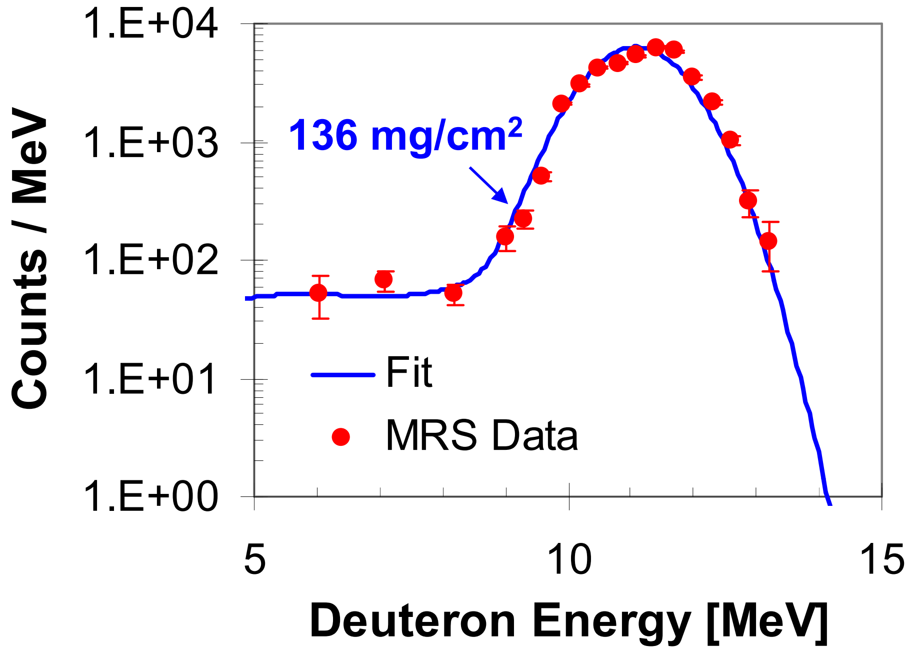
Shots 51316-51320 – ρR_{shell}=65 ± 23 mg/cm^2



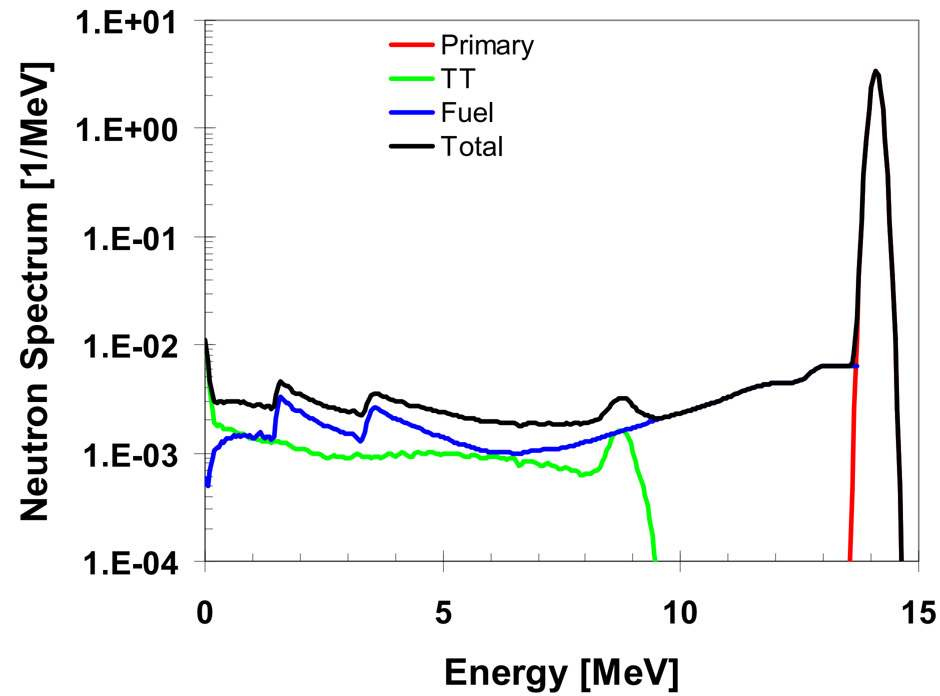


An areal density of 136 ± 23 mg/cm² was inferred from the first down-scattered neutron measurement of a cryogenic DT implosion

53066: CryoDT(68)CD[10], $Y_n \approx 5.8\times10^{12}$



Best fit neutron spectrum



Summary

The first MRS measurements at OMEGA show the diagnostic is performing well

- The MRS was installed on OMEGA in summer 2007 and the neutron shielding installed in spring 2008
- The MRS response function is being characterized using Geant4 and implosions producing DHe^3 protons and primary DT neutrons
- The CCT was developed to dramatically reduce the background (~10-100 times) for down-scattered neutron measurements for the OMEGA MRS
- The first down-scattered neutron measurements of non-cryogenic and cryogenic DT implosions have been successfully performed

Some Important References

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